Potential of Earthworm Burrows to Transmit Injected Animal Wastes to Tile Drains

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ABSTRACT

Subsurface injection of animal manure is a best management practice (BMP) that reduces odors and promotes efficient nutrient usage. In tile-drained fields, however, injected wastes have been observed emerging from tile outlets shortly after application. This appears to be a particular concern in no-till fields where *Lumbricus terrestris* L. are often numerous. Our objective was to determine if burrows created by this earthworm species can contribute to rapid movement of injected wastes to tile drains. A turbine blower was used to force smoke into a 0.6 m-deep tile line in a no-till field and 20 burrows 0.02 to 0.5 m from the tile that emitted smoke, and 18 burrows 0.8 to 4.7 m from the tile that did not produce smoke were flagged. A Mariotte device filled with dyed water was then used to measure infiltration rate for each burrow. Afterwards, plastic replicas of the burrows were made so their proximity to the tile and geometrical properties could be determined. Average infiltration rate for smoke-emitting burrows (128 mL min^{-1}) was twice that of the more distant burrows. Moreover, dyed water was observed in the tile when added to smoke-emitting burrows, but not when added to burrows that did not produce smoke. Thus, earthworm burrows in close proximity to tile lines may expedite transmission of injected wastes offsite. Movement of injected wastes to tiles via earthworm burrows and other preferential flow paths may be reduced by using precision farming to avoid waste application near tile lines or by modifying application procedures.

CONFINED FEEDING OPERATIONS for animal production generate large amounts of manure. Frequently these wastes are stored as slurries in aerobic or anaerobic lagoons and land-applied as a nutrient source for crop production. These liquid wastes can be applied on the soil surface or incorporated with tillage or by direct injection. Because of concerns with odor and nutrient losses in surface runoff, subsurface injection is currently advocated as a BMP in Ohio (Johnson and Eckert, 1995) and elsewhere (Hilborn, 1992). Injection is accomplished using either portable tanks or flexible hose systems with vertical knives or horizontal sweeps that introduce pressurized slurry 10 to 30 cm below ground. Proper installation and maintenance of surface and subsurface drainage systems reportedly reduce the potential losses of manure to streams (Johnson and Eckert, 1995). In Ohio, however, the NRCS and the Ohio Department of Natural Resources have received numerous reports of animal wastes being found in tile outlets and streams shortly after injection, with the problem more frequently observed in no-till than in tilled fields (Widman, 1998).

No-till soils often have more continuous macropores than tilled soils (Ehlers, 1975; Shipitalo and Protz, 1987; Drees et al., 1994; Pagliai et al., 1995), and this might contribute to the rapid movement of injected wastes to tile drains. Preferential flow in macropores has been shown to contribute to rapid movement of pesticides and nutrients to tile drains (Magesan et al., 1995; Kladivko et al., 1999). Cracks have also been implicated in the rapid movement of pesticides to tile lines (Harris et al., 1994) and may also play a similar role with injected animal wastes. In Ontario, movement of liquid animal wastes through soil cracks to tile drains has been identified as significant source of bacterial contamination leading to beach closure (Hilborn, 1992). In the incidents reported in Ohio, however, cracks were not visible nor did application rates exceed the water holding capacity of the soil (Widman, 1998), which could lead to saturated soil conditions and flow of effluent to the tile through the soil matrix porosity.

No-till soils, nevertheless, often have higher earthworm populations, hence more earthworm-formed macropores, than tilled soils. The increased populations are often attributed to the increased amount of surface residue that provides a greater supply of food as well as a cooler, wetter environment more favorable for earthworm survival (Edwards and Bohlen, 1996, p. 271). Applications of slurried animal wastes to soils can further increase the amount of food available to earthworms and have been shown to increase earthworm populations up to 53% (Curry, 1976) and lead to increased burrow numbers (Haraldsen et al., 1994). Lack of tillage can increase the persistence of earthworm burrows, which also increases the total number of earthworm-formed macropores in no-till soils. Furthermore, greater earthworm populations have been noted in tiled fields than in similar undrained fields (Carter et al., 1982), presumably due to improved soil aeration.

Earthworm-formed macropores can have a major influence on water and chemical movement in soil (McCoy et al., 1994; Shipitalo et al., 2000). Unlike cracks, which can close under wet soil conditions, earthworm burrows can continue to function as preferential flow paths (Friend and Chan, 1995). Moreover, studies conducted in Czechoslovakia suggest that earthworm burrows are more numerous in the backfill around tiles and can be hydraulically connected to the drain (Urbánek and Doležal, 1992). Macropores formed by the anecic, earthworm *L. terrestris* can have a particularly large impact on hydrology because of their relatively large diameter, up to 12 mm, and depth of penetration, up to 240 cm (Edwards and Bohlen, 1996, p. 198). Average infiltration rates for *L. terrestris* burrows in an undrained, no-till, corn (*Zea mays* L.) field in Coshocton, OH, ranged from 41 to 1005 mL min^{-1} burrow^{-1} (Shipitalo and Butt, 1999), whereas Wang et al. (1994) reported steady-state infiltration rates of 37 to 284 mL min^{-1} for *L. terrestris* burrows in a Wisconsin corn field. *Lumbricus terrestris* also appears to respond more favor-

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Abbreviation: BMP, best management practice.

ably to a reduction in tillage frequency than other earthworm species (Edwards and Bohlen, 1996, p. 272).

Thus, no-till, slurry application, and tile drainage can increase earthworm populations and the number of earthworm-formed macropores. These macropores have been implicated in the rapid movement of nutrients and pesticides through soils and may play a role in the rapid movement of injected animal wastes to tile drains. Therefore, our objective was to determine if burrows formed by *L. terrestris* in a no-till, tile-drained field can contribute to the movement of injected animal wastes through the soil and if their effectiveness diminishes with distance from the tile. Furthermore, we investigated if earthworm populations, hence the number of burrows, varied with distance from the tile.

MATERIALS AND METHODS

A tile-drained field at a commercial swine (*Sus scrofa*) production facility near Bucyrus, Ohio, was selected for study. Plastic drain tile (10-cm diam.) was installed in this field by trench excavation ≈10 years ago at a depth of 0.6 m and spacing of 9 m. The field was in the fifth year of a 3 yr, corn–soybean [*Glycine max* (L.) Merr.]–wheat [*Triticum aestivum* L.] rotation. Mulch tillage with a straight-shank chisel was used in the spring of the corn years. The soybean and wheat crops were planted no-till. Anaerobic swine lagoon effluent (≈1% solids) was injected ≈20 cm deep once each year at a rate of 37 400 L ha^{-1}. Preliminary investigations by local NRCS and Crawford County Soil and Water Conservation District personnel indicated that swine lagoon effluent applied with either a flexible hose system or a tank wagon injection unit appeared in the tile outlet only a few minutes after the applicator passed over a tile line.

Field experiments were conducted 19 to 20 May 1999, shortly after soybean was planted. In the portion of the field investigated, the soil is Tiro silt loam 2 to 6% slope (fine-silty, mixed, mesic Aeric Epiaqualfs), a somewhat poorly drained soil formed in Wisconsinan glacial lake sediment with calcareous glacial till making up the lower portions of the solum. The permeability of the upper meter of this soil series ranges from 1.5 to 5.1 cm h^{-1}, and decreases to 0.15 to 1.5 cm h^{-1} in the next meter (Steiger et al., 1979).

In order to determine if earthworm burrows could have contributed to the rapid movement of injected effluent to the tile drains, a pit was opened to expose a short segment of tile that was subsequently severed. The upstream portion of the tile was connected to a gasoline engine-powered turbine blower constructed using a turbocharger salvaged from a transport truck (Fig. 1). After the blower was started, an ignited smoke cartridge (Smoke #3C, Superior Signal Company, Spotswood, NJ) that generates ≈1100 m^3 of smoke in 3 min was placed on the intake.[1] Twenty *L. terrestris* burrows with middens that emitted smoke at a distance of 12 to 25 m from the point of smoke introduction were flagged. An additional 18 *L. terrestris* burrows outside of the zone that produced smoke, but not beyond the midpoint between tile lines, were flagged. These burrows were in two transects perpendicular to the tile line that were 22 and 25 m from the point of smoke introduction.

Infiltration rates in individual flagged burrows were measured using the procedures and equipment described and depicted in Shipitalo and Butt (1999). Briefly, the middens were removed and an intake funnel with a flexible spout was firmly inserted into the burrow entrance. A Mariotte-type infiltrometer with a capacity of 6.8 L was used to maintain a constant head of water within the funnel. In order to distinguish which burrows contributed flow to the tile, water added to the smoke-emitting burrows contained Brilliant Blue FCF dye (Flury and Flühler, 1994), in the form of the commercial product Aquashade (Applied Biochemists, Milwaukee, WI), whereas fluorescein dye was used in the water added to the burrows that did not emit smoke. The water level in the infiltrometer was recorded every minute for the first 2 min then every 2 min thereafter for a total of 30 min, or until the water supply was exhausted. Immediately afterwards, dilute formalin (0.08 mol kg^{-1}) was injected into the burrow to expel the resident earthworm. Species, sexual condition, and fresh, live weights of all specimens were noted.

Fig. 1. Turbine blower used to force smoke into the tile line.

One day after measuring infiltration rates, commercial-grade fiberglass resin (no. 58020, U.S. Chemical & Plastics, Canton, OH) was poured into the burrows. After hardening, the burrows were excavated and burrow depth was obtained by measuring the distance from the base of the burrow to the soil surface. Burrow length was total length of the plastic replica, and volume was obtained by weighing the replicas and dividing by the density of the hardened resin. Average diameter was calculated based on burrow volume and length. The minimum distance between the tile line and the burrows was determined by measuring the closest approach of the plastic replicas to the buried tile as observed in the pits during burrow removal. In the case of the burrows that did not produce smoke, however, the buried tile was too distant to be observed in the pits during removal of the burrow replicas. Therefore, this parameter was taken as the shortest distance from the entrance of the burrow to the tile at the soil surface.

[1] Names are necessary to report factually on available data; however, the USDA neither guarantees nor warrants the standard of the product, and the use of the name by USDA implies no approval of the product to the exclusion of others that may also be suitable.

Fig. 2. Smoke emerging from middens in an ≈1 m wide band above the buried tile.

Earthworm populations were measured in five locations in each of two transects perpendicular to the tile line that were 19 and 20 m from the point of smoke introduction. Earthworms were extracted from the soil by slowly sprinkling 8 L of dilute formalin (0.08 mol kg^{-1}) on the soil surface inside 0.5 by 0.5 m quadrats (Baker and Lee, 1993). The first quadrat was adjacent to the tile line and subsequent quadrant were spaced in 1.2-m intervals. A composite fresh, live weight was obtained for all specimens from individual quadrat and the samples were then preserved in formalin prior to species identification.

Data analysis was performed using the Statistical Analysis System (SAS Institute, 1989), with a 0.05 probability level selected as the minimum acceptable for all comparisons.

RESULTS AND DISCUSSION

General Observations

Blowing smoke into the tile was a very effective means of delineating the position of the buried line and associated *L. terrestris* burrows. Smoke was observed emerging from burrow middens in a band about 1 m wide by 35 m long, the presumed end of the tile (Fig. 2). The rate at which smoke was emitted from individual burrows was highly variable, but this was not quantified. Given the short length of time available to mark the burrows (3 min) it was impossible to determine the percentage of burrows within the 1-m-wide band that were emitting smoke. Regardless, many more burrows were observed emitting smoke than were flagged, and only burrows ≥30 cm apart were selected for further investigation. The entrances of many of the smoke-emitting burrows were beyond the approximately 20-cm-wide zone of soil disturbed by tile installation about 10 years earlier.

The fact that smoke emerged from the burrows indicates that they provided a pathway for the movement of air from the tile to the soil surface. Our original plan was to conduct the experiment when the tile line was flowing to determine if dyed water introduced to burrows with the infiltrometer would be carried to the tile outlet, indicating a direct pathway for the movement of water from individual burrows to the tile. Due to a dry spring season, however, the tile was no longer discharging at the time the experiment was conducted. Nevertheless, we began our infiltration tests with the smoke-emitting burrow closest to the outlet (12.4 m), and continued progressively upstream from the outlet. Fourteen minutes after beginning the infiltration test on the second burrow from the outlet (12.6 m), and after a total of only 9.3 L of water had been added to the burrows, Brilliant Blue-dyed water began to emerge from the outlet. Given the distance of the burrows from the outlet, a substantial portion of the dyed water must have entered the tile. Moreover, the permeability rating of the Tiro series (Steiger et al., 1979) suggests it should have taken 12 to 40 h for the water to reach the tile.

We continued to observe dyed water emerging from the outlet during the remainder of the infiltration tests on the smoke-emitting burrows, with the flow rate apparently fluctuating with the infiltration rate in the burrows. It was impossible, however, to confirm if each of the 20 smoke-emitting burrows contributed to the flow in the tile. Next, infiltration tests with fluorescein-dyed water were conducted on the 18 burrows 0.8 to 4.7 m from the tile that did not produce smoke. The tile ceased flowing and no dyed water was observed, indicating that none of this water migrated to the tile line through these macropores.

Live earthworms were expelled from 42% (16 of 38) of the burrows following completion of the infiltration tests. Only one earthworm was retrieved per burrow, all were *L. terrestris*, and 81% were clitellate adults. In eight other instances a dead *L. terrestris* was found blocking the penetration of the resin upon excavation of the impregnated burrows. This combined with entrapment of air and blockage by debris contributed to a success rate of 45% for making complete plastic replicas of the burrows. This was somewhat lower than the 60% success rate reported when Shipitalo and Butt (1999) used this technique, but was substantially higher than the 20% rate reported by McKenzie and Dexter (1993) when using a grid system and excavation to determine the geometrical properties of earthworm burrows.

Most of the burrows were single, nearly vertical channels, but three of the smoke-emitting burrows were Y-shaped with secondary channels intersecting the main channels at depths of 31 to 69 cm. Similarly, at the two sites investigated by Shipitalo and Butt (1999), an average of 5% of the *L. terrestris* were Y-shaped (see their Fig. 3 for a photograph of typical burrow types). The auxiliary channels were included when the geometrical properties of the burrows were determined and contributed to the greater length and significantly greater volume of the smoke-emitting burrows compared to those that did not produce smoke (Table 1). Presumably the entire length and volume of the combined channels would have contributed to the measured infiltration rates. Depth, average diameter, and weight of the resident earthworm were similar among burrows that did and did not emit smoke (Table 1).

Infiltration Capacity and Rate

Cumulative infiltration was highly variable, but the mean was twice as high for smoke-emitting burrows

Table 1. Infiltration and general characteristics of the burrows.

	Cumulative Infiltration	Infiltration rate 2 min	Infiltration rate Final	Infiltration rate Avg.†	Worm weight	Burrow Depth	Burrow Length	Burrow Volume	Burrow Avg. Diam.
	mL	mL min^{-1}			g	cm		cm^3	mm
					Smoke-emitting				
Mean	3541**	158	109*	128**	4.9	84	110	47*	7.5
Range	888–6736	38–416	0–302	30–353	2.6–6.6	63–95	73–188	30–65	6.4–8.6
					No smoke				
Mean	1714	97	52	62	5.0	78	89	30	6.5
Range	189–6653	8–397	4–199	6–256	4.4–5.9	64–92	83–100	22–44	5.7–8.1

*, **, Smoke-emitting means significantly different from no smoke means at $P = 0.05$ and 0.01 levels, respectively.
† Based on actual length of infiltration measurement when <30 min.

than that for those further distance from the tile that did not produce smoke (Table 1). The volume of the infiltrometer (6.8 L), however, was insufficient to supply three of the smoke-emitting and one of the burrows that didn't produce smoke for the full 30 min, with the dyed water being exhausted in as little as 19 min. Therefore, 2-min, final, and average infiltration rates were calculated in order to compare the infiltration characteristics of the two burrow types. The 2-min reading represents the first measurement of infiltration rate since the 1-min reading included the volume required to initially fill the burrow and intake funnel. The final infiltration rate was calculated using the last reading taken for each burrow. Similarly, average infiltration rate was based on the actual length of the infiltration measurement for each burrow when <30 min.

All three measures of infiltration rate were higher for the smoke-emitting burrows than for those that did not produce smoke (Table 1). Although the mean 2-min rate for the smoke-emitting burrows was 1.6 times that of the burrows that did not produce smoke, the means were not significantly different. Mean infiltration rate, however, declined more rapidly from the 2-min to the final reading for burrows that did not emit smoke (46% decrease) than for those that did (31% decrease). This resulted in mean final and average rates for the smoke-emitting burrows that were more than twice that of the burrows that did not produce smoke (Table 1). Regression analysis for individual burrows indicated that infiltration rate declined significantly with time in most instances (26 of 38). No relationship of infiltration rate to time was detected for the remaining 12 burrows.

In general, the geometrical properties of the burrows were poor predictors of their infiltration characteristics as was also the case in the study of Shipitalo and Butt (1999). The only significant correlations noted were for the 2-min infiltration rate with burrow length and volume (Table 2). The weight of the worm that occupied the burrow was also a poor indicator of infiltration rate (Table 2). In contrast, distance from the tile line was highly related to infiltration rate (Fig 3).

Average infiltration rate for individual burrows declined rapidly with distance from the tile line. This rapid decline was mainly attributable to a rapid decrease in infiltration rate for the smoke-emitting burrows, as infiltration rate for the burrows that did not produce smoke varied little (Fig. 3). Thus, production of smoke, although it indicated linkage of the burrow to the tile line, was not a quantitative measure of how closely the burrows were associated with the tile and was not a good predictor of infiltration rate.

The plastic replicas of the burrows revealed that none of the earthworms entered the openings in the tile, but they burrowed as close as 2 cm from the tile (Fig. 3 and

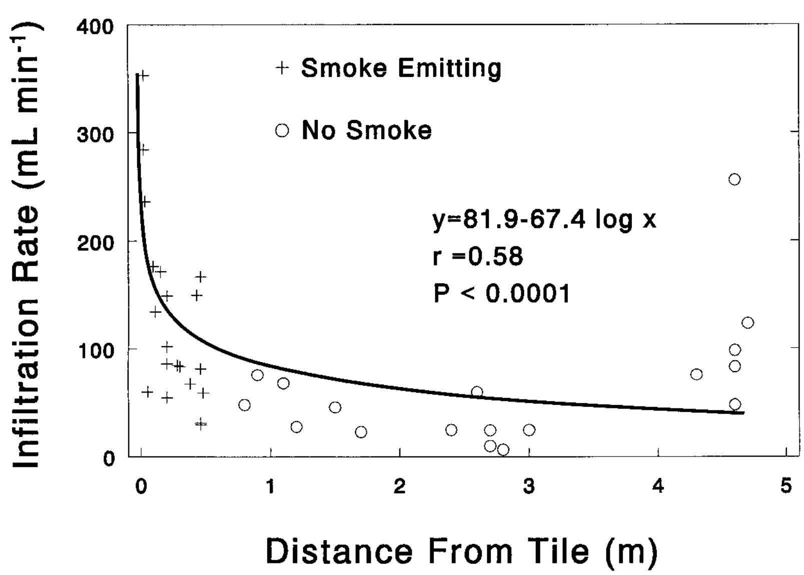

Fig. 3. Average infiltration rate in individual earthworm burrows as a function of distance from the buried tile.

Table 2. Correlation (Pearson's *r*) of infiltration rates with burrow geometrical properties and worm weight.

Variable	Burrow Depth	Burrow Length	Burrow Volume	Burrow Avg. Diam.	Worm weight
Infiltration rate (2 min)	0.12	0.53*	0.49*	0.10	−0.19
Infiltration rate (Final)	−0.09	0.20	0.42	0.35	−0.07
Infiltration rate (Average)	−0.01	0.27	0.48	0.36	−0.10
n	18	18	17	17	16

* Correlation coefficient significant at $P = 0.05$.

4). Therefore, smoke blown into the tile and dyed water used in the burrow infiltration tests must have passed through a portion of the soil matrix porosity. In the case of the dyed water even a short distance of travel through the matrix porosity was sufficient to substantially reduce infiltration rate. One of the burrows at the midpoint between tile lines (4.6 m), however, had an average infiltration rate (256 mL min^{-1}), that was similar to those for burrows nearest the tile that produced smoke (Fig. 3). The plastic replica of this burrow was incomplete because it terminated in a mass of resin-impregnated soil. Excavation of this burrow also revealed that the subsoil in this area was coarser-textured, and gleyed colors were less evident than the soil surrounding the other burrows. This may have been the result of previous disturbance of the soil by burrowing rodents as has been reported by Bouma et al. (1982) and Shipitalo and Butt (1999), or a sedimentological feature. Sand lenses at the contact of the lake deposits with the glacial till have been noted in the Tiro series (Stieger et al., 1979).

Earthworm Populations

There were no detectable trends in earthworm abundance or biomass with distance from the tile line (Table 3). The mean population of 50 earthworms m^{-2} was on the low side of that typically reported for arable fields (Edwards and Bohlen, 1996, p. 96) and the numbers measured by Kladivko et al. (1997) in no-till fields in Indiana and Illinois with soils similar to the Tiro soil we investigated. This may have been related to the dry spring conditions we previously noted. Bohlen et al. (1995) found that measured earthworm populations can decline dramatically in response to drought conditions.

The distribution of *L. terrestris* closely followed that of the total population and their numbers were not influenced by the presence of the tile line (Table 3). Thus, it is unlikely that the number of macropores formed by this earthworm would vary with distance from the tile. *Lumbricus terrestris* comprised an average of 82% of the total earthworm population, and 78% of the specimens were juveniles. The relatively high proportion of *L. terrestris* in the population may have been an artifact of the sampling method or due to the fact that it is more drought-tolerant than other species (Bohlen et al., 1995). Formalin reportedly does not extract all species equally and is most effective on species with wide and deep burrows, such as *L. terrestris* (Baker and Lee, 1993; Edwards and Bohlen, 1996, p. 93). Nevertheless, formalin extraction is useful for comparing relative abundances and is more efficient in no-till than in plowed soils (Baker and Lee, 1993).

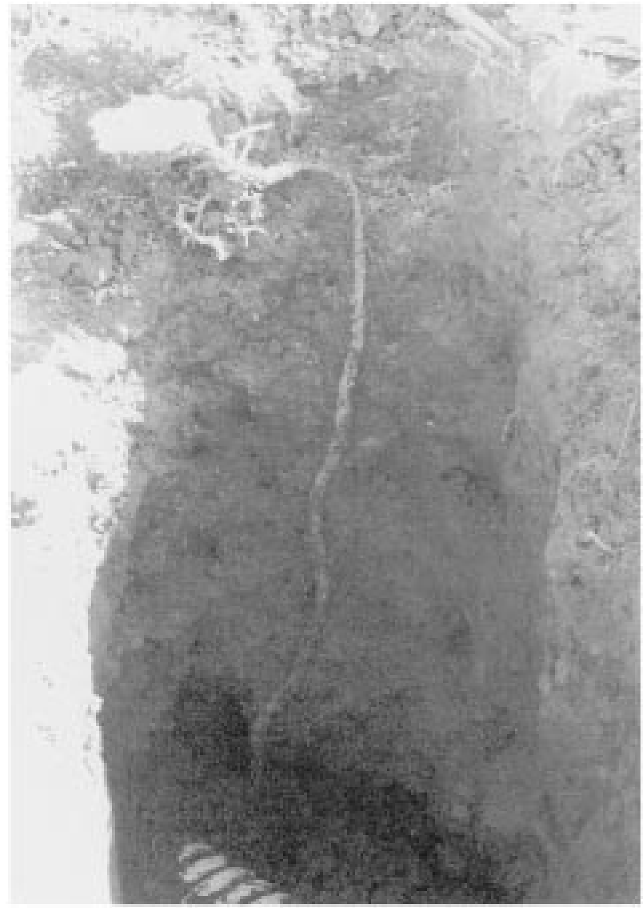

Fig. 4. Earthworm burrow closely associated with the buried tile. This burrow approached within 3 cm of the tile and had an average infiltration rate of 236 mL min^{-1}.

SUMMARY AND CONCLUSIONS

Our results indicate that some *L. terrestris* burrows rapidly transmitted water to the buried tile. The rate at which water entered the burrows declined with the log of their distance from the drain tile. Beyond a distance of about 0.5 m, the tile had no apparent effect on the infiltration rate in the burrows, and water added to

Table 3. Total earthworm population, number of *L. terrestris*, and total earthworm biomass as a function of distance from the tile drain as measured in two transects using 0.5 × 0.5 m quadrats.†

	Distance from tile line (m) 0–0.5	1.2–1.7	2.4–2.9	3.6–4.1	4.8–5.3	Avg.
	Total earthworm population (no. m^{-2})					
Transect 1	72	16	100	44	24	51
Transect 2	72	44	68	28	36	50
Mean	72	30	84	36	30	50
	L. terrestris (no. m^{-2})					
Transect 1	64	12	76	32	24	42
Transect 2	56	32	56	28	32	41
Mean	60	22	66	30	28	41
	Total earthworm biomass (g m^{-2})					
Transect 1	130	24	120	85	61	84
Transect 2	88	83	93	38	93	79
Mean	109	54	107	62	77	82

† No significant differences in means among distances detected at $P = 0.05$.

these burrows did not enter the drain, although the geometrical properties of these burrows were similar to those closer to the tile. Furthermore, the number of earthworms, hence the potential number of earthworm-formed macropores, was not affected by distance from the tile line. The infiltration characteristics of the burrows were poorly correlated to the geometrical properties of the burrows, thus models of infiltration based on these characteristics without taking into account distance to the tile would not accurately predict intake of injected animal manure. Models that simulate the fate of injected animal manure could be improved, however, by incorporating a macropore flow component (Bakhsh et al., 1999).

The infiltration tests were conducted without regard to whether earthworms occupied the burrows, although in most cases (24 of 38) we were able to confirm that a single *L. terrestris* occupied each burrow. Earthworms would probably be present in most burrows when animal manure is injected, therefore these conditions simulate those likely to occur during waste application. Regardless, Shipitalo and Butt (1999) demonstrated that the presence of a live *L. terrestris* had no significant effect on infiltration in their burrows.

It is uncertain how much injected manure can be transmitted to buried tile in *L. terrestris* burrows, or if these are the only type of macropore that contributed to the rapid movement of injected swine lagoon effluent to the tile observed during actual field operations. The highest average infiltration rate we measured for a single burrow was 353 mL min^{-1}. Even at this rate the amount of effluent transmitted to the tile during the short time an injector is in contact with a single burrow would probably be quite small. Nevertheless, since the effluent is injected under pressure the infiltration rates might be much higher, and with an average of 41 *L. terrestris* m^{-2}, the aggregate effect of their burrows may be substantial. Even if the amount of animal waste directly transmitted to the tile might be small in terms of the total application and of no agronomic consequence, their potential to contribute to microbial contamination of surface water might be high enough to be of concern. Furthermore, these burrows might also contribute to rapid movement of pesticides and nutrients to the tile drain when these materials are applied in the vicinity of the tile.

The fact that direct transfer of water from *L. terrestris* burrows to the tile was limited, in this instance, to 0.5 m either side of the tile, suggests several potential solutions that warrant further investigation. If the position of tile lines can be accurately determined, the techniques of precision agriculture might be used to avoid waste application in the immediate vicinity of the tile. This might not be practical in many locations, however, given the layout and spacing of the tile lines relative to the size of the injection equipment. Additionally, this would result in untreated zones in the field that might have lower fertility levels and crop yields. Tillage might also be used to disrupt the burrows in the zone above the tile prior to waste application, and is recommended in Ontario prior to application of liquid wastes to soils with visible cracks (Hilborn, 1992). Tillage has been shown to reduce pesticide losses in tile (Rothstein et al., 1996) and mole drains (Brown et al., 1999). Disruption of the soil, however, would eliminate the benefits of no-till in this zone and would probably reduce the effectiveness of the tile in removing excess water from the field (Patni et al., 1996). Another alternative would be to use shut-off valves to inhibit flow from the tile lines when animal manure is being injected for a long enough period to allow any wastes that enter the tile sufficient time to reenter the soil. This remedy is currently being used in Ohio with cost sharing available through the Ohio Department of Natural Resources. Catch basins could also be installed so that effluent that enters the tile could be collected and reinjected. These techniques should be useful even if macropores other than those formed by *L. terrestris* contribute to rapid movement of injected wastes to tile lines.

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Biomass and Residue Cover Relationships of Fresh and Decomposing Small Grain Residue

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ABSTRACT

Maintaining residue cover provides diverse conservation benefits. Exponential relationships have been developed to estimate cover from biomass of randomly distributed, flat residues, but a large portion of crop biomass remains standing after harvest. Our objective was to determine how relationships between biomass and soil cover change in no-tillage small grain fields as residues decompose and shift from standing to flat. Winter and spring wheat (*Triticum aestivum* L.), winter barley (*Hordeum vulgare* L.), and spring oat (*Avena sativa* L.) were grown at Bushland, TX, on Pullman clay loam (fine, mixed thermic Torrertic Paleustoll) in 12 field plots in three randomized complete blocks. For each crop, differential seeding rate, fertilization, and irrigation produced a range of biomass. During decomposition, differential irrigation increased environmental variability (13, 5, and 0 applications to sub-sub-plots). Ash-free residue biomass was measured seven times in 14 mo, after taking photographs to determine soil cover of 1-m^2 sites. For crop-date combinations, coefficients were determined from total (k_t, m^2 g^{-1}) or flat (k_f, m^2 g^{-1}) biomass. Regression indicated k_t increased with time ($P < 0.0001$ for all crops, except spring wheat with $P < 0.0041$). Across crops, the relationship $k_t = 0.0037 + 0.000047 \cdot \mathrm{DAH}$ ($r^2 = 0.54$, $P < 0.0001$) indicated that decomposition affects cover provided by total biomass. Across crops, the weak relationship $k_f = 0.0136 + 0.000023 \cdot \mathrm{DAH}$ ($r^2 = 0.17$, $P < 0.016$) indicated that cover could be estimated from flat biomass with $k_f \approx 0.0175$ for extended periods. These findings can improve estimation of residue cover for no-tillage fields and indicate that residue orientation should be considered in biomass-to-cover relationships.

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Conservation tillage systems are adopted for a wide variety of reasons, including decreased production costs, decreased labor, and resource conservation. Many natural resource conservation benefits are attained by retaining increased crop residue cover over longer periods of time, including increased infiltration, reduced evaporation, and reduced soil erosion in the short term as well as long-term enhancements in soil organic matter and structure (Steiner, 1994).

Maintaining surface residue cover is often recommended to reduce erosion by water and wind. Residues contribute to erosion control both through sheltering the soil with a nonerodible material (cover) or through changing the surface conformation in ways that change the flow of water and wind across the surface (roughness or resistence). Both aspects are important for both wind and water erosion. The fraction of soil covered by crop residue also influences raindrop impact on soil surface properties (aggregation, crusting, etc.) and on the surface aerodynamic properties (Hagen, 1991). The processes of wind and water erosion are interactive—changes in soil or residue surface properties by either wind or water impacts the erodibility of that surface when exposed to future wind or water erosive forces.

In spite of this complexity, where erosion is primarily by water, the required amount of residue has been based on surface cover (with 30% cover required after planting

Abbreviations: DAH, days after harvest; k_f, flat biomass cover coefficient (m^2 g^{-1}); k_t, total biomass cover coefficient (m^2 g^{-1}); M, residue biomass (g m^{-2}).